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USERS' GUIDE TO THE OAK RIDGE SPREADSHEET BATTLE MODEL

D. S. Hartley III

MAY 1991

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USERS' GUIDE
TO THE OAK RIDGE
SPREADSHEET BATTLE MODEL

D. S. Hartley III

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ABSTRACT

The Oak Ridge Spreadsheet Battle Model (ORSBM) is a combat effects predictor model. Given a description of a battle, it predicts the duration, surprise, advance rate, total advance, casualties, combat systems losses, and victor for the battle. Further, the model produces confidence ranges for each result. The form of the equation used to calculate casualties has been validated; however, the application of the input data to these equations and the other calculations reflect statistical fits to historical data. The historical data are extensive, but not exhaustive. Therefore, using the model to forecast the results of future battles, while providing a superior forecast to other alternatives, will result in inaccuracies.

This document describes version 3 of the ORSBM. The model is implemented as a Lotus 1-2-3 spreadsheet. Separate sections describe the operating instructions, the input requirements, and the output interpretation. An additional section is included that contains the mathematical logic of the model to enable its transference to other spreadsheets or modeling environments.

As a stand-alone model, the ORSBM provides a fast, portable estimator of battle outcomes. In addition, the model can provide the basis for a dynamic simulation of warfare. The spreadsheet model assumes that forces X and Y, supplied by the user, are to fight and yields the estimated results. However, one of the major factors of warfare is the selection and positioning of forces for battle and the timing of the actual engagement. A simulation containing the ORSBM logic could address the majority of its processing to the strategic and logistic issues of war, producing a rapid dynamic simulation.

This paper is the sixth in a series of reports on the breakthrough research in historical validation of attrition in combat. The first report in the series was Historical Support for a Mixed Law Lanchestrian Attrition Model: Helmbolds Ratio, K/DSRD-113, D. S. Hartley III and K. L. Kruse. The second report was The Constraint Model of Attrition, K/DSRD-114, D. S. Hartley III. The third report was Historical Validation of an Attrition Model, K/DSRD-115, D. S. Hartley III. The fourth report was Confirming the Lanchestrian Linear-Logarithmic Model of Attrition, K/DSRD-263, D. S. Hartley III. The fifth report was Predicting Combat Effects, K/DSRD-412, D. S. Hartley III. This last report contains the research upon which the formulas used in the spreadsheet model are based.

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1. INTRODUCTION AND OPERATING INSTRUCTIONS

This document describes version 3 of the Oak Ridge Spreadsheet Battle Model (ORSBM). This model is an empirical (historically based), spreadsheet implemented battle outcome predicting model. It is a static model that predicts the outcome of one battle at a time. This outcome includes the predicted length of the battle; however, the predictions are not based on a dynamic, time stepped process, but on a straightforward set of (mostly linear) equations relating the predictions to the input data.

All of the predictions of the ORSBM are based on a database containing over 600 historical battles [Dupuy, et al., 1] and the analysis of possible causative factors, both numerical and judgmental. Portions of the model are not only historically based, but have been validated against separate sets of data and may be considered very reliable [Hartley, 5]. Portions of the model are based on sparse data and are relatively unreliable. The accuracy of this model is known to be no more than two significant figures for the expected value. When the known random effects are included, the amount of variability in battle results becomes clear. The derivation of the formulas within the ORSBM are found in Hartley [6].

The simplicity of the battle assessment model is based on its empiricism, its orientation to available data, rather than theoretical constructs. The data on warfare that are collected, analyzed, and available for model construction are limited in quantity and in number of attributes for each battle. This model was built from the largest known database that contains a large number of attributes. The putative causal attributes and the outcome attributes of the database define the inputs and outputs of the model.

This simplicity means that the model is both fast running and robust. By not being excessively specific in its predictions, it is more often correct. The philosophy is, "better to be approximately right than exactly wrong." The value of the results is increased by the presentation of confidence intervals for each result.

The construction of the model is based on statistical analyses of historical data and simulations based on these analyses. The model, in turn, can provide the basis for a dynamic simulation of warfare. The spreadsheet model assumes forces X and Y, supplied by the user, are to fight and yields the estimated results. However, one of the major factors of warfare is the selection and positioning of forces for battle and the timing of the actual engagement. A simulation containing the ORSBM could address the majority of its processing to the strategic and logistic issues of war. Such a simulation would be faster than current simulations by many orders of magnitude.

The model is implemented as a Lotus 1-2-3 Release 2.01 spreadsheet. In order to run the model, the user must have a copy of Lotus. It is assumed that the user either understands how to use Lotus or has the Lotus instruction manual and can learn how. The model is loaded in Lotus by using the /File Retrieve command to retrieve the ORSBM3.WK1 file. All of the cells except valid input cells in the model are protected, so that no formulas will be inadvertently destroyed.

To operate the model, simply fill in the desired values for each input cell and press the CALC key. The results may be viewed by using the 'PgDn' key to move through the screens to the output portion of the model. Use the /Print Printer command to print the input and output portions of the model. The proper range is preset. Use the GRAPH key or the /Graph View command to view the Helmbold Space test. To print or plot the Helmbold Space graph, use the /Graph Save command to save the graph to the MODEL.PIC file. Then quit the Lotus portion and use the Printgraph portion of Lotus to print or plot that file.

2. PREPARING THE INPUT

The ORSBM input requires four input screens and two combination input/output screens. The actual number of input variables is fairly small; however, space is taken to identify each input variable and cue the user for the expected value ranges or type of data. The values that are entered by the user are shown in bold face. All other values are explanations or calculated from the input. Space is also reserved to display error indicators. These error indicators only appear after the CALC function key is used. The input values shown in the screen boxes are within the allowed ranges and will not generate error messages; however, all error indicators are shown (in parentheses) to indicate their positions.

2.1 BATTLE IDENTIFICATION

Fig. 1 shows the format of cues and input fields much as they will appear in the spreadsheet. (The Lotus column and row indicators are omitted.) The time and date are displayed in the upper right corner of the screen. These will be updated to reflect the current time and date each time the CALC function key is used. The battle identification is a free format, alphanumeric field which, together with the date and time, allows for scenario definition and connection of the inputs with the outputs. (These identifiers are repeated on the output page.)

c1991	OAK RIDGE BATTLE PREDICTOR			version 3
INPUT DATA	BATTLE IDENTIFICATION **Desert Shield-Jan 15**			01/16/91 RUN DATE 12:26:29 PM RUN TIME
ATTACKER IDENTITY			DEFENDER IDENTITY	
Arabs	**0.1**	c	Arabs	**0**
Austria	**0**	h	Austria	**0**
England	**0.1**	o	England	**0**
European	**0**	i	European	**0**
France	**0.1**	c	France	**0**
Germany	**0**	e	Germany	**0**
Israel	**0**		Israel	**0**
Italy	**0**	=	Italy	**0**
Japan	**0**		Japan	**0**
Russia	**0**	1	Russia	**0**
USA	**0**		USA	**1**
Other	**0.7**		Other	**0**
	(ERR)			(ERR)

Fig. 1. First input screen

2.2 COMBATANTS' IDENTITIES

Fig. 1 also includes the input section for identifying the combatants. The selections and the groupings (*Arabs*, *European*, *Other*) were delineated by the historical data used to create this model. Certain countries had sufficient numbers of battles and differed significantly from other countries in battle results to warrant a separate listing. Other countries either had insufficient battle data or were insufficiently different from others for a separate listing and were grouped with similar countries. As examples, all of the Arab countries are grouped together; countries such

as Greece and Spain are grouped as *European* countries; and most non-European countries are grouped as *Other*.

The selection illustrated shows the attacker coalition of 70% *USA*, 10% *Arabs*, 10% *England*, and 10% *France* (choice = 0.7, 0.1, 0.1, and 0.1, respectively) against *Arabs*, as the defender (choice = 1.0). The zero values for the other choices remove them from the calculations. The total of the fractions for each of the sides must be "1.0." The (ERR) entries in the illustration represent the positions of the error test indicator. If the sum of the choices on a side is 1.0, then that area is blank; otherwise, the area contains the letters "ERR," indicating an error.

2.3 COMBATANTS' FORCES

Fig. 2 is displayed when the "PgDn" key is used from screen one. Screen two includes the input variables for the attacker and the defender forces. These are the number of personnel, the number of armored attack vehicles (tanks and armored guns, but not armored personnel carriers), the number of artillery pieces (cannon, artillery mortars, and multiple rocket launchers), and the number of combat air sorties (single aircraft missions flown in the engagement area against enemy targets by fighters, fighter-bombers, and bombers) to be performed each day. The error indicator appears if the sum of the armor, artillery, and air sorties is greater than 3/4 the total personnel for that side, if the personnel values are less than or equal to zero, or if any of the combat systems values are less than zero.

```
ATTACKER FORCES                                   DEFENDER FORCES
   Personnel                  413000                 Personnel                510000
   Armor                        2485                 Armor                      4000
   Artillery                     943                 Artillery                  2700
   Air Sorties/Day              2000                 Air Sorties/Day             200
                               (ERR)                                           (ERR)

ATTACKER HUMAN FACTORS                            DEFENDER HUMAN FACTORS
   Technology                      2                 Technology                    1
   Leadership                      2                 Leadership                    1
   Morale                          2                 Morale                        1
   Initiative                      2  -2 <---> 2     Initiative                   -1
   Intelligence                    2                 Intelligence                  1
   Combat Effectvness              2                 Combat Effectvness            0
   Logistics                       1
                               (ERR)                                           (ERR)
```

Fig. 2. Second input screen

2.4 COMBATANTS' HUMAN FACTOR VALUES

Fig. 2 also contains the human factors input data. Each factor may range from -2 to +2. Fractional values are permitted, but are probably only justified when a series of battles is being examined, with initial integral values deriving from human judgment and successive values being judged as changes from the initial values depending on the results of the previous battles. The error indicator appears for a side if the value for any factor for that side falls outside that range.

The values should be relative to the time frame of the battle. For instance, the presence of cannon might represent a Technology value of +2 at a time when cannon were relatively unusual, and a value of 0 when cannon were common battle systems. A force with cannon technology on today's battlefield would rate a -2 technology score.

Leadership should be judged from the commander of the given battle down. A value of +2 indicates the presence of leadership on the order of Napoleon. A +1 Leadership value indicates competent, well-trained leaders with a tradition of initiative. The value of -1 should be used for normally ill-trained or "green" leaders and -2 reserved for exceptionally incompetent leadership.

Morale represents the state of the situation, including what has happened previously in the war. Thus troops with previous battle losses might have lower morale than the same troops had for the first battle.

Initiative refers to proactive actions as opposed to reactive actions. The attacker usually has the initiative; however, in a substantial number of situations, especially at the battle level, the defender may have the initiative, for instance by choosing the time and place of the battle.

Intelligence refers to the military capability of gaining and using information concerning the organization, dispositions, intentions, and activities of the forces of the opponent.

Logistics refers to the ability of the forces to obtain and perform resupply in the appropriate time frame. The logistics ability of a force may be good for the first battle of a series, but decline for successive battles. Only the attacker's logistics capability is significant.

Combat effectiveness is a complex judgment factor that is partially redundant when considered together with other factors above; however, it correlates better with some results than does the combination of those factors and is included for that reason. It is an overall judgment about the leadership, training, experience, morale, and logistics of a force and the interaction of these factors. This same effect may be seen in sports teams in which the individual numbers concerning the team don't add up to the overall effectiveness of the team and in teams with exceptionally talented individuals, but without the cohesion of a true team.

2.5 OPERATIONAL DATA

The operational data input variables include the attackers' plan and frontal width, the defender's scheme of defense, the defender's posture, and the air superiority of one or the other side. These variables are found in Fig. 3, obtained by using the "PgDn" key from screen two.

2.5.1 The Attack Plan

Analysis of the historical data yielded the six statistically different attack plans shown in Fig. 3: single envelopment, single envelopment plus frontal attack, double envelopment, double envelopment plus frontal attack, frontal attack, and river crossing. The significance of the difference actually varies depending on the result being modeled. For some results the attack plan makes no discernable difference at all and is not used. For other results it might be the case that only four of the plans are really different in effect. This is modeled by having relatively

close weights for the similar plans. For simple battles, choose one plan and place a one in its position. Larger battles with combination assaults may be represented with fractional values (with total values adding to 1.0). The error indicator appears if the sum of the values does not equal 1.0.

```
                    ------ OPERATIONAL DATA ------

ATTACK PLAN                        c      DEFENSE SCHEME
  Single envelopment        0      h        Strict Defense           1
  S. env + Frontal          0      o        Defense + Offense        0
  Double envelopment        0      i        D/O, S. env              0
  D. env + Frontal          1      c        D/O, D. env              0
  Frontal attack            0      e        D/O, Frontal             0
  Riv Crossing              0      =        D/O, Frntl + S env       0
                        (ERR)      1        D/O, Frntl + D env       0
                                                                 (ERR)

ATTACKER'S WIDTH: km    300.0             DEFENSE POSTURE          8.0
                        (ERR)               Fortified = 8        (ERR)
AIR SUPERIORITY             1               Prepared  = 6
  Defender = -1         (ERR)               Hasty     = 4
  None     =  0                             Delay     = 2
  Attacker =  1                             Withdraw  = 0
```

Fig. 3. Third input screen

2.5.2 The Defense Scheme

The defense scheme was analyzed in the same manner as the attack plan and seven different schemes were found to be significant: strict defense, defense plus a general offensive option, defense plus a single envelopment, defense plus a double envelopment, defense plus a frontal assault, defense plus a combined frontal assault and single envelopment, and defense plus a combined frontal assault and double envelopment. The desired defense scheme or schemes should be chosen in the same way as described for the attack plan. The error indicator appears if the sum of the values does not equal 1.0.

2.5.3 The Attacker's Frontal Width

The attacker's frontal width represents a measure (in kilometers) of the contact zone between the attacker and the defender. (Other measures based on the width are calculated internally.) The error indicator directly below the width value appears only if the width is less than or equal to 0.0.

2.5.4 The Defense Posture

The defense posture is represented on a scale from 0 to 8. The value zero is used when the defender is withdrawing (attempting to disengage from the fighting). The value two is used when the defender is delaying (moving to the rear, but attempting to fight small skirmishes to delay the attacker's advance). The value four is used when the defender has chosen to stand and fight, but has not had time to prepare a defensive position (e.g., foxhole only). The value six is used when the defender has had time to prepare his position (log bunkers, etc.). The value eight is used when the defender has built concrete bunkers or the equivalent. Intermediate and non-integral values may be used either to represent intermediate postures or averages across varying amounts of preparation among the defender's forces. The error indicator appears if the value selected is outside the valid range.

2.5.6 Air Superiority

The final input variable in Fig. 3 is the air superiority variable. The values range from -1.0 to 1.0. If the defender has complete air superiority over the battlefield use -1.0. If no one has air superiority use zero. If the attacker has complete air superiority use 1.0. The error indicator appears directly beneath the air superiority variable if the absolute value of the variable is greater than 1.0.

2.6 ENVIRONMENTAL DATA

The environmental data (climate and season, weather, temperature, and terrain visibility) are found in Fig. 4.

```
                    ----- ENVIRONMENTAL DATA -----
                                                              (ERR)
CLIMATE & SEASON     (ERR)              WEATHER                 2.5
  Temperate - Spring     0                Sunny=1, Overcast=2
  Temperate - Summer     0                Light Rain=3, Heavy Rain=4
  Temperate - Fall       0                                    (ERR)
  Temperate - Winter     0              TEMPERATURE            -0.5
  Non Temperate          1                Cold=-1, Mild=0, Hot=1

TERRAIN VISIBILITY     2.5
  Bare=1, Mixed=2,   (ERR)
  Wooded=3, Urban=4

          ----- BATTLE DATE AND CONFIDENCE INTERVAL -----

STARTDATE                        15-Jan-91
  Day                   15              PERCENT OF CASES (confidence)
  Month                  1        choice 50 80 90 98 99+              3
  Year                  91           use  1  2  3  4  5           (ERR)
```

Fig. 4. Fourth input screen

2.6.1 Climate and Season

The historical data support differentiation among the five combinations of climate and season shown: temperate climate - Spring, temperate climate - Summer, temperate climate - Fall, temperate climate - Winter, and non-temperate climate - all seasons. Generally a battle will fall within only one of these categories and should have a value of one for only one of the categories. However, if after running the model, it is determined that the battle length is sufficient to span two seasons, that span can be indicated with fractional values. The error indicator will appear above the choices if the sum is not equal to 1.0.

2.6.2 Weather

The weather variable ranges from 1 to 4 and may have fractional values to indicate an average value. Sunny weather merits an input of 1.0; overcast weather, a 2.0; light rain, a 3.0; and heavy rain merits a 4.0. The error indicator will appear over the value if it is outside the proper range.

2.6.3 Temperature

The temperature variable ranges from -1 for cold (freezing temperatures) weather to +1 for hot (tropic temperatures) weather. Intermediate values are allowed. The error indicator will appear above the value if it is out of the allowed range.

2.6.4 Terrain Visibility

Terrain visibility is a judgmental variable based on the visibility allowed by the type of terrain occupied by the battlefield. Bare terrain is indicated by a '1.' Mixed bare and wooded terrain is indicated by a '2.' Heavily wooded terrain is indicated by a '3.' Urban terrain is indicated by a '4.' Intermediate or averages for the entire battlefield may be given by non-integral values. The error indicator will appear below the value if it is less than 1.0 or greater than 4.0.

2.7 BATTLE DATE AND CONFIDENCE INTERVAL

The battle starting date and the desired confidence interval also are found in Fig. 4.

The numerical values for the day of the month, the month of the year, and the year are the required inputs for the starting date. Only battles in the twentieth and twenty first centuries are supported (a Lotus restriction on dates). For battles in the twentieth century, input the last two digits of the year. For battles in the twenty first century, add 100 to the last two digits and use the result as the year input. Valid dates will be converted and appear in a day-month-year format as shown. Invalid inputs will result in an error message in that position.

This battle model computes expected values for the results of the input values and also a low and high value based on the expected values and a requested confidence interval size, based on the error distribution of the sub-models. Only the integral values from 1 to 5 are valid. The value one corresponds to a spread containing 50% of the battles (25% above and 25% below the expected value). The values two through five correspond to 80%, 90%, 98%, and 99+% spreads, respectively.

2.8 OUTPUT OVERRIDES

The output values will be discussed in the next section; however, there are optional input values contained in the output section. These will be discussed here. The reason for these optional inputs is that some of the output values are used in calculating other output values and like all the output values, the results are only guesses (based on historical data, but still guesses) and may be wrong. The optional inputs allow the user to override the output value and view the results on dependent variables. The optional overrides include duration, surprise, advance rate, and casualties.

2.8.1 Duration Override

The first output screen, Fig. 5, contains the duration override. A value of '0.0' indicates that no override is intended. Any value greater than 0 is used to replace the duration values in all

subsequent calculations. If the value of the override is less than 0, the error indicator appears below the override value.

```
PREDICTIONS            BATTLE IDENTIFICATION          01/16/91 RUN DATE
                       Desert Shield-Jan 15        12:26:30 PM RUN TIME

DURATION - LOW             2.7 Days
         - EXP             6.6
         - HI             16.0
  DURATION override        0.0
                          (ERR)
SURPRISE - LOW            -0.4  Att. Complete   =3  Def. Complete   =-3
         - EXP             0.8  Att. Substantial=2  Def. Substantial=-2
         - HI              2.2  Att. Minor      =1  Def. Minor      =-1
  SURPRISE override      0.000  None            =0.001 (override)
                          (ERR)

ADVANCE RATE - LOW        32.0 km/day    DISTANCE - LOW          90.0
             - EXP        37.0                    - EXP         100.0
             - HI         43.0                    - HI          100.0
  ADVNC RAT override     0.000
                          (ERR)
```

Fig. 5. First output screen

2.8.2 Surprise Override

The surprise override is also contained in Fig. 5. A value of '0.0' indicates that no override is intended. Because the value of surprise ranges from -3 (complete surprise by the defender) to +3 (complete surprise by the attacker), there is a problem if the user wishes to override the surprise with a 0 surprise value. The special value of '0.001' is chosen to represent this situation. The mathematical effect of this value is the same as a zero surprise value and allows the program to use '0.0' to indicate no override. If the override value is less than -3.0 or greater than 3.0, the error indicator appears below the override value.

2.8.3 Advance Rate Override

The advance rate override is also contained in Fig. 5. A value of '0.0' indicates that no override is intended. Because the value of the advance rate may be virtually in number (negative for advance by the defender and positive for advance by the attacker), there is a problem if the user wishes to override the advance rate with a 0 kilometers/day advance rate value. The special value of '0.001' is chosen to represent this situation. The mathematical effect of this value is the same as a zero advance rate value and allows the program to use '0.0' to indicate no override. Although very large advance rates are conceivable, advance rates larger in absolute value than 100 kilometers/day are unlikely. Gross errors are detectable by displaying the error indicator if the absolute value of the override is greater than 100.

2.8.4 Casualties Override

The casualties override values are in the second output screen, Fig. 6. The attacker casualties and the defender casualties may be overridden; however, if one is overridden, both must be overridden. (If, for some reason, the user wishes to insist that one side has zero casualties, a small positive value, such as '1," must be used.) A value of '0.0' indicates that no override is intended. The error indicator for the attacker casualties will appear if the override value is less than 0 or if it is greater than the number of personnel given as the attacker's starting value.

Similarly, the error indicator for the defender casualties will appear if the override value is less than 0 or if it is greater than the number of personnel given as the defender's starting value. If either override is activated with a positive number and the other is left with a 0 value, the error indicator between the attacker and the defender data will appear.

```
                         --- CASUALTIES AND LOSSES ---
ATT CASUALTIES - LOW       360   k/w/mia   DEF CASUALTIES - LOW      1800
               - EXP      1500                            - EXP      8300
               - HI      11000                            - HI      69000
  ATT CAS override           0               DEF CAS override           0
                         (ERR)     (ERR)                            (ERR)
ATT ARMOR LOST - LOW       580             DEF ARMOR LOST - LOW      2400
               - EXP       630                            - EXP      2400
               - HI        710                            - HI       2500

ATT ARTIL LOST - LOW         0             DEF ARTIL LOST - LOW       300
               - EXP         6                            - EXP       400
               - HI         20                            - HI        500

ATT AIR LOSSES - LOW       100             DEF AIR LOSSES - LOW       100
               - EXP       100                            - EXP       100
               - HI        100                            - HI        100
```

Fig. 6. Second output screen

3. UNDERSTANDING THE OUTPUT

All outputs have restricted numbers of significant digits. This prevents an overestimate of the precision of the results. Lotus is capable of calculating numbers with fifteen significant digits; however, the precision of the sub-models is limited to one or two significant digits. For instance, a casualty prediction of 22000 means somewhere between 21500 and 22500 casualties.

Each output category is based on a submodel for that category. Each submodel has its own valid number of significant digits and its own error distribution. The confidence factor from the input section is used to select the appropriate numerical change for each sub-model, based on its distribution. In this scenario, the confidence level that was input was three, meaning that the spread should be 90%. Thus, for each category, the expected value is displayed, along with a lower and a higher value. These bracketing values are chosen so that, on average, 45% of battles should have values between the lower and the expected values and 45% of battles should have values between the upper and the expected values. (Naturally, this means that 10% of battles could be expected to fall outside of the output range.)

The output of the battle predictor takes two forms. The first is that of the output screens of the spreadsheet. Two of these screens were shown in Fig. 5 and Fig. 6 in the discussion of output overrides in the input section. The third output screen is shown below in Fig. 7. Because the two output forms have the same format and data content, the detailed descriptions are in the following paragraphs concerning the second output form.

```
                    --- PREDICTING VICTORY ---

ADVANTAGE - LOW          2.1
          - EXP          5.0
          - HI           8.0

          VICTOR - LOW                  >> ATTACKER <<
                 - EXP                  >> ATTACKER <<
                 - HI                   >> ATTACKER <<
```

The predictions should be used in conjunction with the graph that places this battle within the context of the historical data used to produce the predictions. The three data points representing "This Battle" show the low, expected, and high predictions. When the points fall within the "Core group" ellipse, the results may be given a high confidence level. If the points fall outside the "Outer limit" ellipse, "This Battle" is too far from the underlying data for good predictions.

Fig. 7. Third output screen

The second form of output of the battle predictor is the printed output. The printed output is divided into two pages. The first page displays the input data and the second page displays the results. Fig. 8, below, illustrates the makeup of the first page of the printed output. The left side of the page contains a boxed image of the four screens of input data. The right side of the page contains abbreviated versions of the input instructions and comments given in the input section of this manual.

```
c1991          OAK RIDGE BATTLE PREDICTOR              version 3     Fast running, based on historical data

INPUT DATA          BATTLE IDENTIFICATION          01/16/91 RUN DATE
                    Desert Shield-Jan 15        12:26:29 PM RUN TIME Time and date of computed battle results

ATTACKER IDENTITY                          DEFENDER IDENTITY         Country groups are based on availability
  Arabs                 0.1   c             Arabs                1      of historical data.
  Austria               0     h             Austria              0   "Arabs" is the group of Arab countries.
  England               0.1   o             England              0   "European" is the group of European
  European              0     i             European             0      countries not otherwise listed.
  France                0.1   c             France               0   "Other" includes all other countries.
  Germany               0     e             Germany              0   Choose the single predominant country when
  Israel                0                   Israel               0      more than one is on a side or apply
  Italy                 0     =             Italy                0      fractional values to each country so
  Japan                 0                   Japan                0      that the sum of attacker values is 1.0
  Russia                0     1             Russia               0      and the sum of defender values is 1.0.
  USA                   0.7                 USA                  0
  Other                 0                   Other                0

ATTACKER FORCES                            DEFENDER FORCES
  Personnel          413000                 Personnel       510000   Personnel includes support personnel.
  Armor                2485                 Armor             4000   Armor includes armored assault guns, but
  Artillery             943                 Artillery         2700      does not include armored transport.
  Air Sorties/Day      2000                 Air Sorties/Day    200   Artillery includes MRLS type launchers.
                                                                     Each flight of a fighter or bomber.

ATTACKER HUMAN FACTORS                     DEFENDER HUMAN FACTORS
  Technology              2                 Technology           1   Rate the capability of each side.
  Leadership              2                 Leadership           1      -2 is very bad, +2 is very good.
  Morale                  2                 Morale               1      Fractional values are allowed.
  Initiative              2 -2 <---> 2      Initiative          -1
  Intelligence            2                 Intelligence         1
  Combat Effectvness      2                 Combat Effectvness   0   Overall fighting capability
  Logistics               1

                  ------ OPERATIONAL DATA ------

ATTACK PLAN                   c            DEFENSE SCHEME            Choose the single attack plan and the
  Single envelopment      0   h             Strict Defense       1      single defense scheme that best
  S. env + Frontal        0   o             Defense + Offense    0      describes each side's plans.
  Double envelopment      0   i             D/O, S. env          0
  D. env + Frontal        1   c             D/O, D. env          0
  Frontal attack          0   e             D/O, Frontal         0
  Riv Crossing            0   =             D/O, Frntl + S env   0
                              1             D/O, Frntl + D env   0

ATTACKER'S WIDTH: km   300.0               DEFENSE POSTURE     8.0   Fractional width values are allowed.
                                            Fortified = 8            Defense postures between the values given
AIR SUPERIORITY           1                 Prepared  = 6               may be specified.
  Defender = -1                             Hasty     = 4
  None     =  0                             Delay     = 2
  Attacker =  1                             Withdraw  = 0

                 ----- ENVIRONMENTAL DATA -----

CLIMATE & SEASON                           WEATHER             2.5   Choose one climate and season combination.
  Temperate - Spring      0                 Sunny=1, Overcast=2      The small amount of non temperate data in
  Temperate - Summer      0                 Light Rain=3, Heavy Rain=4  the database does not permit seasons.
  Temperate - Fall        0                                          Fractional weather values are allowed.
  Temperate - Winter      0                TEMPERATURE        -0.5   Fractional temperature values are allowed.
  Non Temperate           1                 Cold=-1, Mild=0, Hot=1

TERRAIN VISIBILITY      2.5                                          Fractional terrain visibility values are
  Bare=1, Mixed=2,                                                      allowed.
  Wooded=3, Urban=4

           ----- BATTLE DATE AND CONFIDENCE INTERVAL -----

STARTDATE                      15-Jan-91                             For year>1999, use 100 + last two digits.
  Day                    15             PERCENT OF CASES (confidence)   (e.g., for year=2055, use 155 for year)
  Month                   1      choice 50 80 90 98 99+          3   Confidence interval is a rough
  Year                   91         use  1  2  3  4  5                  approximation of standard deviation.
```

Fig. 8. Output page 1, input data

Fig. 9 illustrates the makeup of the second page of the printed output. Like the first page, the left side of the page contains a boxed image of screen data, in this case the three output screens, and the right side of the page contains abbreviated instructions and comments. In addition, the bottom section contains an abbreviated discussion of the Helmbold Space test, described in more detail below.

```
PREDICTIONS          BATTLE IDENTIFICATION          01/16/91 RUN DATE
                     Desert Shield-Jan 15         12:26:30 PM RUN TIME

DURATION - LOW            2.7 Days                                      Predicted duration range.
         - EXP            6.6
         - HI            16.0
  DURATION override       0.0                                           Override for subsequent calculations.

SURPRISE - LOW           -0.4  Att. Complete    =3  Def. Complete    =-3   Fractional surprise values have inter-
         - EXP            0.8  Att. Substantial=2  Def. Substantial=-2       mediate interpretations.
         - HI             2.2  Att. Minor       =1  Def. Minor       =-1
  SURPRISE override     0.000  None             =0.001 (override)          Override for subsequent calculations.
                                                                             (Use 0.001 for a 0 override.)

ADVANCE RATE - LOW       32.0 km/day      DISTANCE - LOW        90.0    The distance is a function of the advance
             - EXP       37.0                      - EXP       100.0       rate and the duration.
             - HI        43.0                      - HI        1( ).0
  ADVNC RAT override    0.000                                           Override for subsequent calculations.
                                                                          (Use 0.001 for a 0 override.)
                    --- CASUALTIES AND LOSSES ---

ATT CASUALTIES - LOW      320   k/w/mia   DEF CASUALTIES - LOW    1600  Casualties include killed, wounded in
               - EXP     1300                            - EXP    7300     action, missing in action, and captured.
               - HI      9300                            - HI    61000
  ATT CAS override          0               DEF CAS override         0  Both attacker and defender casualties must
                                                                           be overridden simultaneously.
ATT ARMOR LOST - LOW      530             DEF ARMOR LOST - LOW    2400
               - EXP      630                            - EXP    2400
               - HI       710                            - HI     2500

ATT ARTIL LOST - LOW        0             DEF ARTIL LOST - LOW     300
               - EXP        6                            - EXP     400
               - HI        20                            - HI      500

ATT AIR LOSSES - LOW       90             DEF AIR LOSSES - LOW     100
               - EXP      100                            - EXP     100
               - HI       100                            - HI      100

                    --- PREDICTING VICTORY ---
                                                                        Advantage ranges from -8 for absolute
ADVANTAGE - LOW           2.1                                              defender advantage to 8 for absolute
          - EXP           6.0                                              attacker advantage.
          - HI            8.0
                                                                        |Advantage| > 1 predicts victor.
        VICTOR - LOW                      >> ATTACKER <<
               - EXP                      >> ATTACKER <<
               - HI                       >> ATTACKER <<

   The predictions should be used in conjunction with the graph that
places this battle within the context of the historical data used to
produce the predictions.  The three data points representing "This
Battle" show the low, expected, and high predictions.  When the
points fall within the "Core group" ellipse, the results may be given
a high confidence level.  If the points fall outside the "Outer limit"
ellipse, "This Battle" is too far from the underlying data for good
predictions.
```

Fig. 9. Output page 2, results

The upper third of the results page corresponds to the first output screen. The battle identification and date/time data are repeated to connect the results to the input page, should they become separated. (The run time may be identical or a second later than the run time on the input page.)

The Duration predictions consist of the expected value and the low and high estimates, given in days. In this example, the estimates range from 2.7 days to 16.0 days with an expected value of 6.6 days. The Duration override value of 0.0 indicates that the predicted duration values were not overridden. The duration predictions are based on input values as described in the calculations section of this manual. Note that only two significant digits are justified in the duration sub-model.

The Surprise predictions range from a low of -0.4 (very minor defender surprise) to a high of 2.2 (substantial surprise by the attacker) with an expected value of 0.8 (minor attacker surprise). The surprise override was not used in this scenario. The surprise predictions are based on input values as described in the calculations section of this manual. Note that two significant digits are output.

The Advance Rate predictions are based on the input values and the predicted (or override) surprise values. The predictions range from a low of 32.0 kilometers/day (attacker advance) to a high of 43.0 km/day, with an expected value of 37.0 km/day. Lotus does not permit the standard indication of significant digits to be output. The number of significant digits here is actually two (43.0 should be represented by 43.) The advance rate override of 0.000 indicates that the advance rate predictions have not been overridden.

The expected Distance prediction is a function of the expected advance rate and the expected duration. The number of significant digits is only one for total distance.

The middle third of the results page corresponds to the second output screen and contains the casualties and combat systems losses predictions. The casualty predictions are based on total casualties, including killed, wounded, missing in action, and captured. These predictions are based on the input data, the predicted (or overridden) duration, and the predicted (or overridden) advance rate. The attacker and defender casualty override values are both 0, indicating the casualty predictions have not been overridden. Note that only two significant digits are output.

The predictions for casualties and victory are the most "accurate" predictions made by the model in the sense that the combined expected value predictions and range predictions for these elements have theoretical components that have been validated against multiple datasets. The other predictions are the best fits available for a large set of data; however, they have not been validated against a second set of data.

The predictions for attacker and defender losses of armor, artillery, and aircraft follow the same pattern of expected, low, and high predictions. These values are based on the input data and the output data discussed above. Armor losses have two significant digits while artillery and aircraft losses have only one. The aircraft loss predictions are the least reliable of all the predictions because the historical data was sparsest in this area.

The bottom third of the results page corresponds to the third output screen. Its principal contents are the victory predictions. The Advantage predictions are used to predict the victor. The values for advantage range from -8 for an absolute advantage for the defender to +8 for an absolute attacker advantage. In the illustrated scenario, the predicted advantage ranges from a low of 2.1 to a high of 8.0, with an expected value of 6.0. Advantage is converted to a victory prediction by selecting the defender as the predicted victor when the advantage value is less

than -1, the attacker as the victor when advantage is greater than 1, and calling the battle a draw otherwise. In this case, the expected winner is the attacker, with both the low ant the high side predictions being for the attacker also.

The final part of the bottom third of the results page is a discussion of a method for determining whether the input scenario falls reasonably well within the historical data that were used to create the battle predictor model. Because interpolation is a more reliable prediction method than extrapolation, predictions based on scenarios that are within the historical data space are more likely to be nearly correct than those falling well outside the historical data space.

This data space, called Helmbold Space, is illustrated in Fig. 10. The solid ellipse contains the core group of the historical data. The ellipse of boxes contains the majority of the remainder of the historical data. If all of the historical data were plotted in the graph using the same scale symbols, the interior of the solid ellipse would appear completely covered and the space between the solid ellipse and the boxed ellipse would show a decreasing density from the inside out. Only a few data points would appear outside the boxed ellipse.

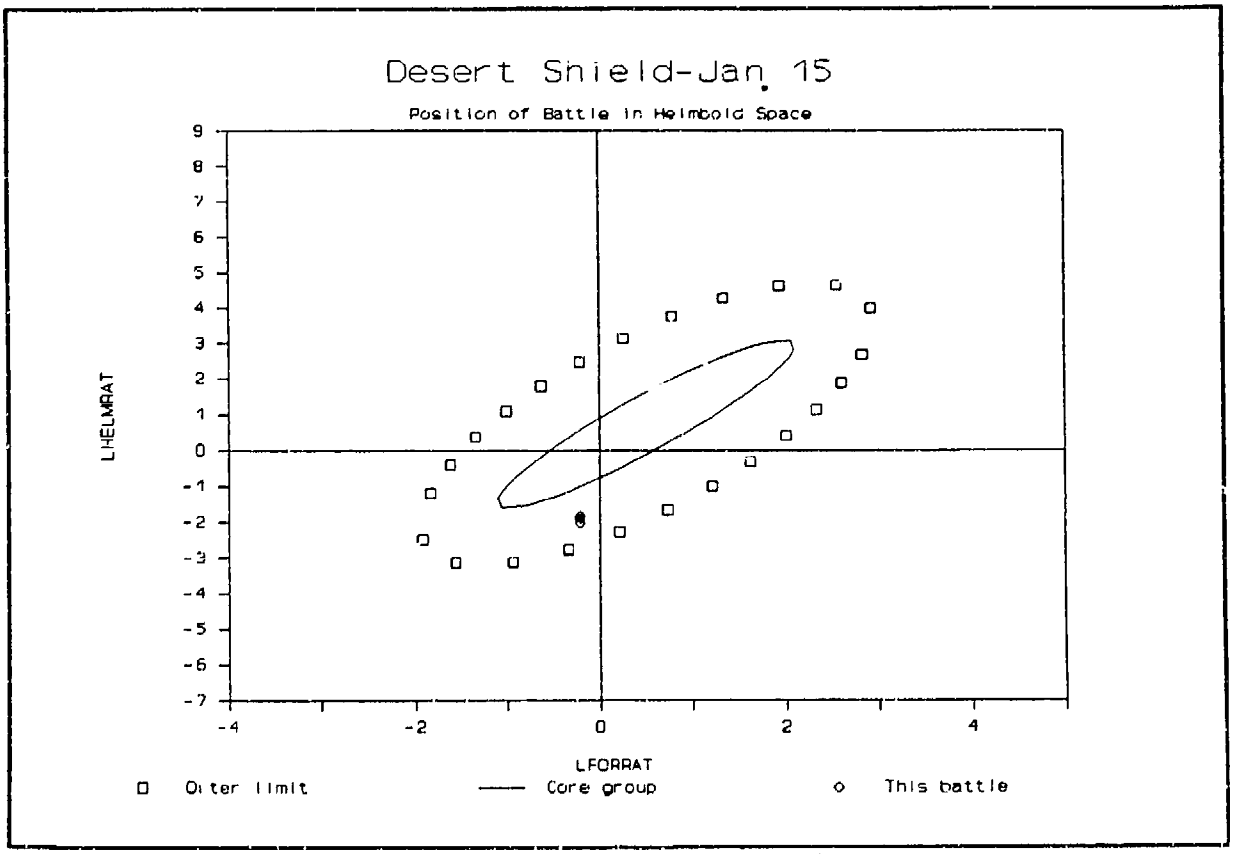

Fig. 10. Output results in Helmbold Space

The range of the predicted results from the current model scenario is shown by the three diamonds (representing the low, expected, and high predictions). In this case the predictions

are relatively close together and fall between the two ellipses. The results of this test are that the predictions may be given a moderate level of confidence.

This figure may be viewed within the spreadsheet by using the GRAPH option. It may also be plotted or printed using the appropriate spreadsheet options.

4. VARIABLES AND FORMULAE

This section contains the calculations used in creating the spreadsheet battle model. It has two purposes. The first is to explain the calculations for any user interested in how the results are derived. (More complete information on the derivation and the rationale may be found in the Hartley [6].) The second reason is to permit the re-creation of the model in some other spreadsheet besides Lotus 1-2-3 or in some other modeling environment.

The validity of the results of the ORSBM is based on accurate statistical fitting of the historical data. In addition, the validity depends on things assumed to be true. These assumptions may be stated as follows:

ASSUMPTION 1: There are "laws" of battle.

ASSUMPTION 2: Except for minor effects, these "laws" are stable over time.

ASSUMPTION 3: These "laws" may be approximated by relatively simple functions of observable factors.

ASSUMPTION 4: The data in the LWDB sample are reasonably representative of the population of battle data.

ASSUMPTION 5: The human judgements in the LWDB that produced the quantitative judgment variable values are reasonably accurate. That is, other groups of military historians would generate similar values.

ASSUMPTION 6: The variance in assigning quantified judgments to current forces and situations would not be excessively larger than the variance for past forces and situations.

Lotus does not use variable names in the same way that most programming languages do. In a Lotus spreadsheet, the primary method of refering to a value is by its cell name, a column letter and row number. Lotus does provide a secondary naming method, in which cells may be assigned range names. These range names perform the same function as variable names; however, practical restrictions to range names arise from the retention of cell names. For instance, in the work which defined the formulas for the ORSBM, a variable was named "DP3." This is a valid range name for Lotus (that is no error occurs in assigning it); however, it is also a valid cell name, which takes precedence (sometimes). Thus some variables required renaming for Lotus. These instances are noted as they occur below.

4.1 INPUT VARIABLES AND INTERMEDIATE CALCULATED VARIABLES

The identities of the attacker and defender are referred to by the variables ATTACKER and DEFENDER, although there are actually no such variables in the spreadsheet implementation of

the logic. In the spreadsheet, each of the possible attackers and defenders has a variable which holds the input for that choice. This procedure will be more fully explained at the first example of its use.

The names of the input variables in the attacker and defender forces section are listed in Box 1.

Box 1. Force size input variables

X0	=	attacker's personnel
X0TARM	=	attacker's armor
X0ART	=	attacker's artillery
X0SORTD	=	attacker's daily sorties
Y0	=	defender's personnel
Y0TARM	=	defender's armor
Y0ART	=	defender's artillery
Y0SORTD	=	defender's daily sorties

The names of the input variables in the attacker and defender human factors section are listed in Box 2.

Box 2. Human factors input variables

XTECHN	=	attacker's technology
XLEAD	=	attacker's leadership
XMORAL	=	attacker's morale
XINITI	=	attacker's initiative
XINTEL	=	attacker's intelligence
XCE	=	attacker's combat effectiveness
XLOGIS	=	attacker's logistics
YTECHN	=	defender's technology
YLEAD	=	defender's leadership
YMORAL	=	defender's morale
YINITI	=	defender's initiative
YINTEL	=	defender's intelligence
YCE	=	defender's combat effectiveness

The variables for the attack plan, MAINATK, the defense scheme, DSCHEME, and the climate-season combination, SEASON, are implemented in the same way as the attacker and defender variables. The other operational data and environmental data input variables are listed in Box 3. The defense posture has the range name DEFPOS3 in Lotus because DP3 is a valid cell name; however, the equations using it in this section will generally refer to it as DP3.

Box 3. Operational and environmental input variables

WIDTH	=	defender's frontal width
DEFPOS3	=	defense posture
AIRSUPQ3	=	air superiority
WEATHER3	=	weather
TEMP	=	temperature
VIS	=	terrain visibility

The battle date and confidence interval data input variables are listed in Box 4. The date that is displayed in the model as the starting date uses the Lotus @DATE function as shown. In the internal structure of Lotus, the value of STARTDATE is actually an integer representing the number of days after January 1, 1900. The equations used to calculate the predictions in the model were developed in the SAS language, which uses a similar date representation. The SAS date value is based on January 1, 1960. Hence where the date value in [6] is simply the coded value of the battle's starting date, in Lotus the coded date value is too large a number and must be reduced by the days between January 1, 1900 and January 1, 1960. The variable STDDEV contains the confidence level desired by the user. Depending on the error distribution or the particular combat effect, this may be translated into a standard deviation value or some other error approximation. The two alternatives will be discussed more fully at the first examples of each situation.

Box 4. Date and confidence level input variables

DAY	=	day
MONTH	=	month
YEAR	=	year
STARTDATE	=	@DATE(YEAR, MONTH, DAY)
STARTDAT	=	STARTDATE - 21916.
STDDEV	=	confidence level

The five override values for output variables are listed in Box 5.

Box 5. Override input variables

DUROVER	=	override for the duration values
SURPOVER	=	override for the surprise values
ADVROVER	=	override for the advance rate values
CASXOVER	=	override for the attacker casualty values
CASYOVER	=	override for the defender casualty values

In addition to the attacker and defender human factors variables, there is a need for comparative human factors variables, derived from the human factors variables. These are defined in Box 6. The variable COMEFF, the comparative combat effectiveness, is called CE3 in the research [6]; however, that variable name is a valid celnn name in Lotus.

Box 6. Derived human factors variables

TECHNOL3	=	XTECHN - YTECHN
LEADER3	=	XLEAD - YLEAD
MORALE3	=	XMORAL - YMORAL
COMEFF	=	XCE - YCE
INITIAT3	=	XINITI - YINITI
INTEL3	=	XINTEL - YINTEL

Several variables that proved valuable in the formulation of the attrition function are shown in Box 7.

Box 7. Derived variables from previous research

FORRAT	=	X0/Y0
LFORRAT	=	ln(X0/Y0)
HELMRAT	=	$(X0^2 - (X0 - CASX)^2)/(Y0^2 - (Y0 - CASY)^2)$
LHELMRAT	=	ln(HELMRAT)
V	=	LHELMRAT -2*LFORRAT
PSV	=	1-1/(1 + exp(-1.75*sign(V)*abs(V)**.75))

First order derivative variables that are used in the prediction equations are defined in Box 8.

Box 8. Simple derived variables

ABAIRSUP	=	abs(AIRSUPQ3)
ABTECHNL	=	abs(TECHNOL3)
AREA	=	$WIDTH^2/3$
ART	=	X0ART+Y0ART
FDURAT	=	min(DURATION,40)
LARTFR	=	ln((1 + X0ART)/(1 + Y0ART))
LCASX	=	ln(CASX)
LCASY	=	ln(CASY)
LDUR	=	ln(DURATION)
LSORTFR	=	ln((0.1 + X0SORT)/(0.1 + Y0SORT))
LWID	=	ln(WIDTH)
LX0	=	ln(X0)
LY0	=	ln(Y0)
MANPERK	=	(X0 + Y0)/(WIDTH*2)
RX0	=	sqrt(X0)

Several variables are logical functions of other variables, as shown in Box 9.

Box 9. Simple logical derived variables

if X0TARM = 0 and Y0TARM = 0	then ARMOR = 0 else ARMOR = 1
if X0SORT = 0 and Y0SORT = 0	then AIRPL = 0 else AIRPL = 1
if XSUCCESS > 1	then VICTOR = "A"
if XSUCCESS < -1	then VICTOR = "D"
if -1 <= XSUCCESS <= 1	then VICTOR = "N"

The second order derived variables (derived from first order derived variables and input variables) are defined in Box 10.

Box 10. Second order derived variables

ABAIWEAT	=	ABAIRSUP*WEATHER3
ABAIYART	=	ABAIRSUP*Y0ART
CYART	=	(CASY/1000)*ART
KPERMAN	=	1/MANPERK
LFDURAT	=	ln(FDURAT)
LWIDYART	=	LWID*Y0ART
LXXARM	=	LX0*X0TARM
LYYARM	=	LY0*Y0TARM
RX0DP	=	RX0*DP3
STOFFARM	=	(STARTDAT + 17000)*ARMOR
SUATOT	=	SURPRIS3*RX0
SULF	=	SURPRIS3*LFORRAT
XCELW	=	XCE*LWID
XYSORTD	=	(X0/1000)*Y0SORTD
YXARM	=	(Y0/1000)*X0TARM
YXSORTD	=	(Y0/1000)*X0SORTD

4.2 CALCULATING DURATION

DURATION PROPOSITION: The logarithm of a battle's duration is a function of the following variables: the presence of aircraft, the battle's starting date, the temperature, the product of the square root of the attacker's force size and the defensive posture, the product of the absolute value of air superiority and the defender's artillery, the product of the logarithm of the attacker's width and the defender's artillery, the attacker's nationality, the defender's nationality, and a normal random variable. The duration is the exponential of the log duration. The equations in Box 11 estimate this relationship.

It must be noted that extension of the duration forecast beyond the date of the last battle in the database is **extrapolation**, which is less reliable than **interpolation**. The sense of the STARTDAT variable in the model is for longer battles as time progresses. Conservative forecasts should consider this factor.

Box 11. Duration proposition

```
P_ln(DURAT) = .31 + .24*AIRPL + .0000083*STARTDAT - .157*TEMP
        + .00043*sqrt(X0)*DP3 - .00047*abs(AIRSUPQ3)*Y0ART
        + .000054*ln(WIDTH)*Y0ART + .91*ATVAL + .96*DEVAL
        + normal random variate

P_DURAT = exp(P_ln(DURAT))

normal random variate
        Mean      0
        Std Dev   0.52
```

The variables ATVAL and DEVAL are defined in Box 12 and Box 13, respectively. These definitions are given logically. As was discussed earlier, the implementation of the variables ATTACKER and DEFENDER in Lotus is indirect.

When the attacker or defender identity is significant, as is the case here, each of the country input variables (ranging from 0.0 to 1.0 in value) is multiplied by the value given in the box for that nationality and the sum over the choices is calculated. Thus, if one nation is the attacker, that choice will have an entry of 1.0 and all others will have zero entries. The value given in Lotus to ATVAL, for instance, will be the sum of products and will result in the value associated with the chosen nation. If multiple nations were chosen, ATVAL would have the weighted average of the national values.

Box 12. ATVAL definition

if ATTACKER = 'Arabs'	then ATVAL =	-.5
if ATTACKER = 'Austria'	then ATVAL =	.2
if ATTACKER = 'England'	then ATVAL =	.2
if ATTACKER = 'European'	then ATVAL =	.4
if ATTACKER = 'France'	then ATVAL =	.0
if ATTACKER = 'Germany'	then ATVAL =	.0
if ATTACKER = 'Israel'	then ATVAL =	.3
if ATTACKER = 'Italy'	then ATVAL =	.8
if ATTACKER = 'Japan'	then ATVAL =	.0
if ATTACKER = 'Other'	then ATVAL =	-.1
if ATTACKER = 'Russia'	then ATVAL =	.2
if ATTACKER = 'USA'	then ATVAL =	.0

Box 13. DEVAL definition

if DEFENDER = 'Arabs'	then DEVAL =	-.6
if DEFENDER = 'Austria'	then DEVAL =	-.0
if DEFENDER = 'England'	then DEVAL =	-.0
if DEFENDER = 'European'	then DEVAL =	.2
if DEFENDER = 'France'	then DEVAL =	-.3
if DEFENDER = 'Germany'	then DEVAL =	-.1
if DEFENDER = 'Israel'	then DEVAL =	-.2
if DEFENDER = 'Italy'	then DEVAL =	.1
if DEFENDER = 'Japan'	then DEVAL =	.4
if DEFENDER = 'Other'	then DEVAL =	-.1
if DEFENDER = 'Russia'	then DEVAL =	.1
if DEFENDER = 'USA'	then DEVAL =	.0

Box 11 indicates that the error distribution for the natural logarithm of duration is normal with a mean of zero and a standard deviation of 0.52. This distribution is used in the ORSBM to create a low log duration and a high log duration (and then low and high durations) using the input confidence level.

A table of standard deviations gives the information that 50% of the observations in a normal distribution will fall between -0.68 and 0.68 standard deviations. Similarly, 80% lie between -1.28 and 1.28, 90% between -1.65 and 1.65, and 98% between -2.33 and 2.33. More than 99% lie between -3 standard deviations and 3 standard deviation. Accordingly, the confidence inputs are converted to the appropriate numbers of standard deviations and multiplied by the value of

the log duration standard deviation of 0.52. The results are applied to the expected log duration to produce low and high log durations. All three predictions are expressed with two significant digits.

Because the duration and log duration values are used in predicting other combat effects and a duration override input is allowed, intermediate variables are required. These variables are defined in Box 14. The suffixes LO, EX, and HI indicate the low, expected, and high values, respectively. Variables containing LDUR in the name are log duration variables and others are duration variables.

Box 14. Combination of duration predictions and the override

Predicted MDURLO	=	DUROVER, if DUROVER > 0, DURATLO, otherwise,
Predicted MDUREX	=	DUROVER, if DUROVER > 0, DURATEX, otherwise,
Predicted MDURHI	=	DUROVER, if DUROVER > 0, DURATHI, otherwise,
Predicted MLDURLO	=	ln(DUROVER), if DUROVER > 0 LDURLO, otherwise,
Predicted MLDUREX	=	ln(DUROVER), if DUROVER > 0 LDUREX, otherwise,
Predicted MLDURHI	=	ln(DUROVER), if DUROVER > 0 LDURHI, otherwise.

4.3 CALCULATING SURPRISE

SURPRISE PROPOSITION: Surprise in battle is a function of the following: the attacker's width divided by the average of the forces, initiative, military intelligence, the defensive posture, air superiority, the product of the logarithm of the attacker's forces and the attacker's armor, and a random variate. The equation in Box 15 estimates this relationship

Box 15. Surprise proposition

P_SURP = 260*(WIDTH*2)/(X0 + Y0) + .27*INITIAT3 + .64*INTEL3
+ .034*DP3 - .20*AIRSUPQ3 - .000029*ln(X0)*X0TARM
+ random variate

random variate

Mean	0.	Std Dev	0.79
Skewness	0.83	Kurtosis	0.81

Quantiles

100%	Max	2.9	99% 2.0		Range	5.2
75%	Q3	0.44	95% 1.56		Q3-Q1	0.90
50%	Med	-0.26	90% 1.32		Mode	-0.44
25%	Q1	-0.47	10% -0.66			
0%	Min	-2.3	5% -1.07			
			1% -1.74			

The error distribution for the surprise prediction is not normal. Instead of using the standard deviation as described in the duration calculations, the direct quantile figures can be used. The quantile labeled Min in Box 15 is the minimum (maximum negative) error in the database. This value when algebraicly added to the expected surprise prediction, together with a similar sum involving the Max quantile, produces a spread covering 99+% of the variation. The Q1 quantile refers to a value higher than 25% of the error distribution and the Q3 quantile refers to a value higher than 75% of the error distribution. Thus 50% of the distribution lies between them (roughly, considering end points). Similarly, the 80% confidence level corresponds to the range between the 10% and 90% quantiles, the 90% level to that between the 5% and 95% quantiles, and the 98% level to that between the 1% and 99% quantiles.

The direct use of quantiles just described would be appropriate if the error distribution were for the entire population, instead of the sample available. Because the quantiles are taken from a sample, their direct use is modified by the standard deviation technique for a normal distribution, described in the duration calculations. The (heuristic) procedure is to calculate the values produced by each method and average them, weighted 2/3 standard deviation and 1/3 direct quantile.

Surprise (in the LWDB database) is defined with a range from -3.0 to +3.0; however, for calculations of other quantities involving the predicted surprise, it is permitted a slightly larger range and is thus restricted to -3.5 to +3.5. The output predictions are restricted to one decimal place.

Because the user is allowed to override the predicted surprise values, intermediate, modified surprise values are used in subsequent calculations, computed as shown in Box 16.

Box 16. Combination of the surprise prediction and the override

Predicted MSURPLO =	SURPOVER, if SURPOVER < 0, SURPOVER, if SURPOVER > 0, SURPLO, if SURPOVER = 0.
Predicted MSURPEX =	SURPOVER, if SURPOVER < 0, SURPOVER, if SURPOVER > 0, SURPEX, if SURPOVER = 0.
Predicted MSURPHI =	SURPOVER, if SURPOVER < 0, SURPOVER, if SURPOVER > 0, SURPHI, if SURPOVER = 0.

To allow the user to override the predicted surprise value with a value of 0, the user must override with a value of 0.001, which tests as non-zero, enabling the override, but produces essentially the same calculated effects as a 0 override.

4.4 CALCULATING ADVANCE RATE

ADVANCE RATE PROPOSITION 1: Retreat is often associated with functions of the following variables: the defensive posture, leadership, morale, and the attacker's armor. The equations in Box 17 estimate these functions.

Box 17. Advance rate proposition 1

$$\text{NEGADVN1} = \begin{cases} -1, & \text{if DP3} < 4, \\ 1, & \text{if DP3} > 6, \\ 0, & \text{otherwise.} \end{cases}$$

$$\text{NEGADVN4} = \begin{cases} 1, & \text{if LEADER3} < 0, \\ -1, & \text{if LEADER3} > 0, \\ 0, & \text{otherwise.} \end{cases}$$

$$\text{NEGADVN5} = \begin{cases} -1, & \text{if MORALE3} > 0, \\ 1, & \text{if MORALE3} < 0, \\ 0, & \text{otherwise.} \end{cases}$$

$$\text{NEGADVN7} = \begin{cases} -1, & \text{if X0TARM} > 0, \\ 0, & \text{otherwise.} \end{cases}$$

$$\text{NEGADVNA} = 0.30 - 0.35^{*}\text{NEGADVN4} - 0.24^{*}\text{NEGADVN5} - 0.26^{*}\text{NEGADVN7}$$

$$\text{NDA3} = \text{NEGADVNA}^{3}$$

ADVANCE RATE PROPOSITION 2: The direction of the advance is a function of the following variables: the log of the attacker's width, initiative, the artillery force ratio, NEGADVNA, the product of surprise and the force ratio, and the absolute value of technology. The equation in Box 18 estimates this relationship.

Box 18. Advance rate proposition 2

$$\text{P\_ADRAT\_DIR} = -.173 + .084^{*}\ln(\text{WIDTH}) + .169^{*}\text{INITIAT3} - .038^{*}\ln((1 + \text{X0ART})/(1 + \text{Y0ART})) + .86^{*}\text{NEGADVNA} + .101^{*}\text{P\_SURP}^{*}\ln(\text{X0}/\text{Y0}) - .26^{*}\text{abs}(\text{TECHNOL3})$$

ADVANCE RATE PROPOSITION 3: The magnitude of the advance rate is a function of the following variables: NDA3, the attacker's width, the attacker's forces, the square of the attacker's width, NEGADVN1, and the product of the attacker's combat effectiveness and the attacker's width. The equation in Box 19 estimates this relationship.

Box 19. Advance rate proposition 3

$$\text{P\_ADRAT\_MAG} = .92 + 6.8*\text{NDA3} + .054*\text{WIDTH} - .0000051*\text{X0}$$
$$- .000147*\text{WIDTH}^2/3 - 1.48*\text{NEGADVN1} + .60*\text{XCE}*\ln(\text{WIDTH})$$

if $\text{P\_ADRAT\_MAG} < 0$ then $\text{P\_ADRAT\_MAG} = 0$

ADVANCE RATE PROPOSITION 4: The advance rate is a function of the product of the direction of advance and a function of the magnitude of the advance rate and a random variate. The equation in Box 20 estimates this relationship.

Box 20. Advance rate proposition 4

$$\text{P\_ADRAT} = \text{P\_ADRAT\_DIR}*(1.26 + .85*\text{P\_ADRAT\_MAG}) + \text{random variate}$$

random variate

Mean	0.	Std Dev	4.0
Skewness	2.5	Kurtosis	18.9

Quantiles

100%	Max 31.	99%	16.8	Range	48.
75%	Q3 0.65	95%	5.2	Q3-Q1	1.94
50%	Med -0.30	90%	2.8	Mode	-1.00
25%	Q1 -1.3	10%	-2.9		
0%	Min -16.6	5%	-4.9		
		1%	-10.8		

The error distribution for advance rate is not normal and is calculated in the same fashion as the distribution for surprise. The three prediction are restricted to two significant digits.

Because the user is allowed to override the predicted advance rate values, intermediate, modified advance rate values are used in subsequent calculations, computed as shown in Box 21.

Box 21. Combination of the advance rate prediction and the override

Predicted MADVRLO =	ADVROVER, if ADVROVER < 0, ADVROVER, if ADVROVER > 0, ADVR1LO, if ADVROVER = 0.
Predicted MADVREX =	ADVROVER, if ADVROVER < 0, ADVROVER, if ADVROVER > 0, ADVR1EX, if ADVROVER = 0.
Predicted MADVRHI =	ADVROVER, if ADVROVER < 0, ADVROVER, if ADVROVER > 0, ADVR1HI, if ADVROVER = 0.

To allow the user to override the predicted advance rate value with a value of 0, the user must override with a value of 0.001, which tests as non-zero, enabling the override, but produces essentially the same calculated effects as a 0 override.

4.5 CALCULATING DISTANCE

TOTAL ADVANCE PROPOSITION: The total advance is a function of the product of the advance rate and the duration, and a random variate. The equation in Box 22 estimates this relationship.

Box 22. Total advance proposition

P_ADVANCE = .44*P_ADRAT*P_DURAT + random variate

random variate

Mean	5.7	Std Dev	32.
Skewness	3.1	Kurtosis	55.

Quantiles

100% Max	310.	99%	156.	Range	630.
75% Q3	3.4	95%	29.	Q3-Q1	3.8
50% Med	0.72	90%	11.7	Mode	0.
25% Q1	-0.41	10%	-2.1		
0% Min	-320.	5%	-3.9		
		1%	-33.		

The error distribution is not normal and is calculated in the same way as for surprise. The three output predictions are restricted to one significant digit.

4.6 CALCULATING CASUALTIES

The calculations for attacker casualties and defender casualties are similar in approach, but differ in detail.

4.6.1 Attacker Casualties

ATTRITION THEOREM 1: Attrition in sufficiently large battles follows a homogeneous linear-logarithmic Lanchestrian law. The differential equations for the attrition are stated in the equations in Box 23.

Box 23. Attrition theorem 1

$$dx/dt = -e^{C}*X_0^{.75}*Y_0^{.40}$$
$$dy/dt = -e^{F}*X_0^{.40}*Y_0^{.75}$$

ATTRITION PROPOSITION 1: The variable C is a function of the following variables: duration, log duration, the product of a function of the starting date and the

presence of armor, leadership, the log of the attacker's width, the product of the absolute value of air superiority and weather, the attacker's nationality, the defender's nationality, and the defense scheme. The equation in Box 24 estimates this relationship.

It must be noted that extension of the C forecast beyond the date of the last battle in the database is **extrapolation**, which is less reliable than **interpolation**. The sense of the STARTDAT variable in the model is for lower casualties as time progresses. Conservative forecasts should consider this factor.

Box 24. Attrition proposition 1

```
P_C = -2.7 + .0102*P_DURAT + .42*P_ln(DURAT)
      - .000080*(STARTDAT + 17000)*ARMOR - .39*LEADER3
      - .26*ln(WIDTH) - .106*abs(AIRSUPQ3)*WEATHER3
      + .99*CATVAL + .97*CDEVAL + .95*CDSCHVAL
```

The CATVAL, CDEVAL, and CDSCHVAL variables are defined in Box 25, Box 26, and Box 27, respectively. The CATVAL and CDEVAL variables are calculated as defined for the ATVAL and DEVAL variables of the duration prediction. The CDSCHVAL variable is calculated in a similar manner, using the values for the defense scheme, rather than the national identity.

Box 25. CATVAL definition

if ATTACKER = 'Arabs'	then CATVAL =	1.7
if ATTACKER = 'Austria'	then CATVAL =	.1
if ATTACKER = 'England'	then CATVAL =	.1
if ATTACKER = 'European'	then CATVAL =	.2
if ATTACKER = 'France'	then CATVAL =	.3
if ATTACKER = 'Germany'	then CATVAL =	.3
if ATTACKER = 'Israel'	then CATVAL =	1.2
if ATTACKER = 'Italy'	then CATVAL =	-.5
if ATTACKER = 'Japan'	then CATVAL =	.7
if ATTACKER = 'Other'	then CATVAL =	.1
if ATTACKER = 'Russia'	then CATVAL =	.9
if ATTACKER = 'USA'	then CATVAL =	.0

Box 26. CDEVAL definition

if DEFENDER = 'Arabs'	then CDEVAL = -.8
if DEFENDER = 'Austria'	then CDEVAL = .2
if DEFENDER = 'England'	then CDEVAL = -.3
if DEFENDER = 'European'	then CDEVAL = .2
if DEFENDER = 'France'	then CDEVAL = .0
if DEFENDER = 'Germany'	then CDEVAL = -.2
if DEFENDER = 'Israel'	then CDEVAL = -1.0
if DEFENDER = 'Italy'	then CDEVAL = -.1
if DEFENDER = 'Japan'	then CDEVAL = -.3
if DEFENDER = 'Other'	then CDEVAL = -.1
if DEFENDER = 'Russia'	then CDEVAL = .2
if DEFENDER = 'USA'	then CDEVAL = .0

Box 27. CDSCHVAL definition

if DSCHEME = 'D'	then CDSCHVAL = -1.0
if DSCHEME = 'D/O'	then CDSCHVAL = -.2
if DSCHEME = 'D/O, E'	then CDSCHVAL = -.4
if DSCHEME = 'D/O, EE'	then CDSCHVAL = -.6
if DSCHEME = 'D/O, F'	then CDSCHVAL = -.8
if DSCHEME = 'D/O, F, E'	then CDSCHVAL = -.4
if DSCHEME = 'D/O, F, EE'	then CDSCHVAL = .0

ATTRITION COROLLARY 1: The log of the attacker's attrition is a function of C, the log of the attacker's force size, the defender's force size, and a normal random variate. The attacker's casualties are the exponential of the log casualties. The equations in Box 28 estimate the attacker's casualties.

Box 28. Attrition corollary 1

P_ln(CASX) = P_C + .75*ln(X0) + .4*ln(Y0) + normal random variate

P_CASX = exp(P_ln(CASX))

if P_CASX > X0 then P_CASX = X0 - 1

normal random variate
Mean 0
Std Dev 0.86

The natural logarithm of the attacker's casualties has a normal error distribution. Accordingly, low and high values for it are calculated as described for the log duration. These are extended to casualty values by exponentiation. The output values are restricted to two significant digits.

The availability of the casualty override option requires modified variables for intermediate quantities in other computations. These are shown in Box 29. As before, the LO, EX, and HI suffixes stand for low, expected, and high predictions. The CX and CASX portions of the names indicate attacker (X) casualties and LCAS refers to a log casualty variable.

Box 29. Combination of the predicted attacker casualties and the override

Predicted MCXLO	=	CASXOVER, if CASXOVER > 0, CASXLO, otherwise.
Predicted MCXEX	=	CASXOVER, if CASXOVER > 0, CASXEX, otherwise.
Predicted MCXHI	=	CASXOVER, if CASXOVER > 0, CASXHI, otherwise.
Predicted LCASXLO	=	ln(CASXOVER), if CASXOVER > 0, LCASX3LO, otherwise.
Predicted LCASXEX	=	ln(CASXOVER), if CASXOVER > 0, LCASX3EX, otherwise.
Predicted LCASXHI	=	ln(CASXOVER), if CASXOVER > 0, LCASX3HI, otherwise.

4.6.2 Defender Casualties

ATTRITION PROPOSITION 2: The variable F is a function of the following variables: log duration, combat effectiveness, the product of a function of the starting date and the presence of armor, NEGADVNA, the log of the attacker's width, the average troop strength divided by the attacker's width, the product of the absolute value of air superiority and weather, the attacker's initiative, the attacker's nationality, the defender's nationality, the season, and the attack plan. The equation in Box 30 estimates this relationship.

It must be noted that extension of the F forecast beyond the date of the last battle in the database is **extrapolation**, which is less reliable than **interpolation**. The sense of the STARTDAT variable in the model is for lower casualties as time progresses. Conservative forecasts should consider this factor.

Box 30. Attrition proposition 2

$$
\begin{aligned}
\text{P\_F} = {} & -4.1 + .60 * \text{P\_ln(DURAT)} + .197 * \text{CE3} \\
& - .000093 * (\text{STARTDAT} + 17000) * \text{ARMOR} + 1.04 * \text{NEGADVNA} \\
& - .35 * \ln(\text{WIDTH}) - .000041 * (\text{X0} + \text{Y0}) / (\text{WIDTH} * 2) \\
& - .117 * \text{abs(AIRSUPQ3)} * \text{WEATHER3} + .46 * \text{XINITI} + 1.06 * \text{FATVAL} \\
& + .97 * \text{FDEVAL} + 1.16 * \text{FSEAVAL} + .96 * \text{FATKVAL}
\end{aligned}
$$

The FATVAL, FDEVAL, FSEAVAL, and FATKVAL variables are defined in Box 31, Box 32, Box 33, and Box 34, respectively. The FATVAL and FDEVAL variables are calculated as defined for the ATVAL and DEVAL variables of the duration prediction. The FSEAVAL variable is calculated in a similar manner, using the values for the climate-season, rather than the national identity. The FATKVAL variable is calculated using the values for the attack plan.

Box 31. FATVAL definition

```
if ATTACKER = 'Arabs'     then FATVAL =   -.9
if ATTACKER = 'Austria'   then FATVAL =    .2
if ATTACKER = 'England'   then FATVAL =   -.3
if ATTACKER = 'European'  then FATVAL =    .2
if ATTACKER = 'France'    then FATVAL =    .1
if ATTACKER = 'Germany'   then FATVAL =    .1
if ATTACKER = 'Israel'    then FATVAL =    .3
if ATTACKER = 'Italy'     then FATVAL =   -.7
if ATTACKER = 'Japan'     then FATVAL =   -.6
if ATTACKER = 'Other'     then FATVAL =   -.0
if ATTACKER = 'Russia'    then FATVAL =    .1
if ATTACKER = 'USA'       then FATVAL =    .0
```

Box 32. FDEVAL definition

```
if DEFENDER = 'Arabs'     then FDEVAL =   -.1
if DEFENDER = 'Austria'   then FDEVAL =    .2
if DEFENDER = 'England'   then FDEVAL =   -.0
if DEFENDER = 'European'  then FDEVAL =    .4
if DEFENDER = 'France'    then FDEVAL =    .3
if DEFENDER = 'Germany'   then FDEVAL =   -.2
if DEFENDER = 'Israel'    then FDEVAL =   2.5
if DEFENDER = 'Italy'     then FDEVAL =   -.2
if DEFENDER = 'Japan'     then FDEVAL =   1.0
if DEFENDER = 'Other'     then FDEVAL =    .1
if DEFENDER = 'Russia'    then FDEVAL =    .5
if DEFENDER = 'USA'       then FDEVAL =    .0
```

Box 33. FSEAVAL definition

if SEASON = '-'	then FSEAVAL = .2
if SEASON = 'FT'	then FSEAVAL = -.1
if SEASON = 'ST'	then FSEAVAL = .2
if SEASON = 'SpT'	then FSEAVAL = .3
if SEASON = 'WT'	then FSEAVAL = .0

Box 34. FATKVAL definition

if MAINATK = 'E'	then FATKVAL = .5
if MAINATK = 'E, F'	then FATKVAL = .2
if MAINATK = 'EE'	then FATKVAL = .7
if MAINATK = 'EE, F'	then FATKVAL = .5
if MAINATK = 'F'	then FATKVAL = .2
if MAINATK = 'RivC'	then FATKVAL = .0

ATTRITION COROLLARY 2: The log of the defender's casualties is a function of F, the log of the attacker's force size, the log of the defender's force size, and a normal random variate. The defender's casualties are the exponential of the log casualties. The equations in Box 35 estimate the defender's casualties.

Box 35. Attrition corollary 2

P_ln(CASY) = P_F + .4*ln(X0) + .75*ln(Y0) + normal random variate

P_CASY = exp(P_ln(CASY))

if P_CASY > Y0 then P_CASY = Y0 - 1

normal random variate
Mean 0
Std Dev 0.92

The natural logarithm of the defender's casualties has a normal error distribution. Accordingly, low and high values for it are calculated as described for the log duration. These are extended to casualty values by exponentiation. The output values are restricted to two significant digits.

The availability of the casualty override option requires modified variables for intermediate quantities in other computations. These are shown in Box 36. As before, the LO, EX, and HI suffixes stand for low, expected, and high predictions. The CY and CASY portions of the names indicate defender (Y) casualties and LCAS refers to a log casualty variable.

Box 36. Combination of the predicted defender casualties and the override

Predicted MCYLO	=	CASYOVER, if CASYOVER > 0, CASYLO, otherwise.
Predicted MCYEX	=	CASYOVER, if CASYOVER > 0, CASYEX, otherwise.
Predicted MCYHI	=	CASYOVER, if CASYOVER > 0, CASYHI, otherwise.
Predicted LCASYLO	=	ln(CASYOVER), if CASYOVER > 0, LCASY3LO, otherwise.
Predicted LCASYEX	=	ln(CASYOVER), if CASYOVER > 0, LCASY3EX, otherwise.
Predicted LCASYHI	=	ln(CASYOVER), if CASYOVER > 0, LCASY3HI, otherwise.

4.7 CALCULATING COMBAT SYSTEM LOSSES

There are three combat systems addressed by the spreadsheet battle model: armor, artillery, and aircraft. The losses in each system are calculated for both the attacker and the defender.

4.7.1 Attacker Armor Losses

ARMOR LOSS PROPOSITION 1: The attacker's armor loss is a function of the following variables: the product of the attackers combat effectiveness and the log of the attacker's width, the product of the defender's force size and the attacker's armor, the product of the log of the attacker's force size and the attacker's armor, the attacker's nationality, the attacker's armor, and a random variate. The equations in Box 37 estimate the attacker's armor losses.

Box 37. Armor loss proposition 1

```
P_ARMLOSX = -18.0 - 25*XCE*ln(WIDTH) + .00029*(Y0/1000)*X0TARM
        + .0178*ln(X0)*X0TARM + .96*AMXATVAL

if P_ARMLOSX > . then P_ARMLOSX = max(0,min(P_ARMLOSX,X0TARM))

P_ARMLOSX = P_ARMLOSX + random variate

random variate
        Mean         -4.1      Std Dev     60.
        Skewness      1.24     Kurtosis    13.1

                Quantiles

        100%  Max      400.       99%      230.      Range    690.
        75%   Q3         2.8      95%       66.      Q3-Q1     20.
        50%   Med        0.0      90%       30.      Mode       0.
        25%   Q1       -17.4      10%      -48.
        0%    Min     -290.        5%      -94.
                                   1%     -184.
```

The definition for AMXATVAL is given in Box 38.

Box 38. AMXATVAL definition

```
if ATTACKER = 'Arabs'       then AMXATVAL =   0.
if ATTACKER = 'Austria'     then AMXATVAL =   0.
if ATTACKER = 'England'     then AMXATVAL =  20.
if ATTACKER = 'European'    then AMXATVAL = 130.
if ATTACKER = 'France'      then AMXATVAL = -90.
if ATTACKER = 'Germany'     then AMXATVAL =  40.
if ATTACKER = 'Israel'      then AMXATVAL =  60.
if ATTACKER = 'Italy'       then AMXATVAL =  20.
if ATTACKER = 'Japan'       then AMXATVAL =  40.
if ATTACKER = 'Other'       then AMXATVAL =   0.
if ATTACKER = 'Russia'      then AMXATVAL =  70.
if ATTACKER = 'USA'         then AMXATVAL =   0.
```

The error distribution for attacker armor losses is not normal, so the calculations are performed as described for the surprise calculations. The output values are restricted to two significant digits.

4.7.2 Defender Armor Losses

ARMOR LOSS PROPOSITION 2: The defender's armor loss is a function of the following variables: the defender's armor, the attacker's logistics, the product of the log of the defender's force size and the defender's armor, the defender's nationality, and a random variate. The equations in Box 39 estimate the defender's armor losses.

Box 39. Armor loss proposition 2

P_ARMLOSY = 11.4 - 1.11*Y0TARM + 30*XLOGIS + .129*ln(Y0)*Y0TARM + .96*AMYDEVAL

if P_ARMLOSY > . then P_ARMLOSY = max(0,min(P_ARMLOSY,Y0TARM))

P_ARMLOSY = 1.01*P_ARMLOSY + random variate

random variate

Mean	0.3	Std Dev	37.
Skewness	2.2	Kurtosis	27.

Quantiles

100% Max	330.	99%	115.	Range	490.
75% Q3	0.68	95%	48.	Q3-Q1	4.5
50% Med	0.0	90%	24.	Mode	0.
25% Q1	-3.8	10%	-18.2		
0% Min	-164.	5%	-47.		
		1%	-134.		

The definition of AMYDEVAL is given in Box 40.

Box 40. AMYDEVAL definition

```
if DEFENDER = 'Arabs'     then AMYDEVAL = 10.
if DEFENDER = 'Austria'   then AMYDEVAL =  0.
if DEFENDER = 'England'   then AMYDEVAL =-30.
if DEFENDER = 'European'  then AMYDEVAL = 10.
if DEFENDER = 'France'    then AMYDEVAL =-30.
if DEFENDER = 'Germany'   then AMYDEVAL =-10.
if DEFENDER = 'Israel'    then AMYDEVAL =-10.
if DEFENDER = 'Italy'     then AMYDEVAL =  0.
if DEFENDER = 'Japan'     then AMYDEVAL =-10.
if DEFENDER = 'Other'     then AMYDEVAL =  0.
if DEFENDER = 'Russia'    then AMYDEVAL = 40.
if DEFENDER = 'USA'       then AMYDEVAL =  0.
```

The error distribution for defender armor losses is not normal, so the calculations are performed as described for the surprise calculations. The output values are restricted to two significant digits.

4.7.3 Attacker Artillery Losses

ARTILLERY LOSS PROPOSITION 1: The attacker's artillery loss is a function of the following variables: the square of the attacker's width, the log of the attacker's casualties, the defender's initiative, the attacker's width, the defender's force size, the product of the defender's casualties and the total artillery, the attacker's nationality, the defense scheme, the attacker's artillery force, and a random variate. The equations in Box 41 estimate the attacker's artillery losses.

Box 41. Artillery loss proposition 1

```
P_ARTLOSX = -8.2 + .00168*WIDTH²/3 + 1.50*P_ln(CASX)
        + 15.3*YINITI - .27*WIDTH + .000098*Y0
        - .0000162*(P_CASY/1000)*(X0ART + Y0ART) + .94*ATXATVAL
        + .98*ARTDSCH

if P_ARTLOSX > . then P_ARTLOSX = max(0,min(P_ARTLOSX,X0ART))

P_ARTLOSX = 1.01*P_ARTLOSX + random variate

random variate
        Mean        -.6     Std Dev    17.6
        Skewness    4.4     Kurtosis   44.

                Quantiles

        100%   Max      162.     99%      88.     Range     282.
        75%    Q3         0.0    95%      13.1    Q3-Q1       3.8
        50%    Med       -0.1    90%       1.20   Mode        0.
        25%    Q1        -3.8    10%      -9.8
        0%     Min     -120.     5%      -16.1
                                 1%      -30.
```

The definitions of ATXATVAL and ARTDSCH are given in Box 42 and Box 43, respectively.

Box 42. ATXATVAL definition

```
if ATTACKER = 'Arabs'      then ATXATVAL =   5.
if ATTACKER = 'Austria'    then ATXATVAL =  10.
if ATTACKER = 'England'    then ATXATVAL =   0.
if ATTACKER = 'European'   then ATXATVAL =   5.
if ATTACKER = 'France'     then ATXATVAL =  -5.
if ATTACKER = 'Germany'    then ATXATVAL =   0.
if ATTACKER = 'Israel'     then ATXATVAL =   0.
if ATTACKER = 'Italy'      then ATXATVAL = -15.
if ATTACKER = 'Japan'      then ATXATVAL =  -5.
if ATTACKER = 'Other'      then ATXATVAL =   5.
if ATTACKER = 'Russia'     then ATXATVAL =   5.
if ATTACKER = 'USA'        then ATXATVAL =   0.
```

Box 43. ARTDSCH definition

if DSCHEME = 'D'	then ARTDSCH = 0.
if DSCHEME = 'D/O'	then ARTDSCH = 15.
if DSCHEME = 'D/O, E'	then ARTDSCH = 5.
if DSCHEME = 'D/O, EE'	then ARTDSCH = 5.
if DSCHEME = 'D/O, F'	then ARTDSCH = 0.
if DSCHEME = 'D/O, F, E'	then ARTDSCH = 50.
if DSCHEME = 'D/O, F, EE'	then ARTDSCH = 0.

The error distribution for attacker artillery losses is not normal, so the calculations are performed as described for the surprise calculations. The output values are restricted to one significant digit.

4.7.4 Defender Artillery Losses

ARTILLERY LOSS PROPOSITION 2: The defender's artillery loss is a function of the following variables: the defender's casualties, the attacker's casualties, the defender's force size, the attacker's force size, the duration of the battle, the defender's nationality, the defender's artillery, and a random variate. The equations in Box 44 estimate the defender's artillery losses.

Box 44. Artillery loss proposition 2

```
P_ARTLOSY = .0023*P_CASY - .0022*P_CASX + .00103*Y0 - .00055*X0
        + 4.4*P_DURAT + .99*ATYDEVAL

if P_ARTLOSY > . then P_ARTLOSY = max(0,min(P_ARTLOSY,Y0ART))

P_ARTLOSY = 1.31*P_ARTLOSY + random variate

random variate
        Mean        -14.4      Std Dev    118.
        Skewness    -1.02      Kurtosis    46.

                Quantiles

        100%  Max      1070.      99%      280.      Range    2100.
        75%   Q3         0.0      95%       46.      Q3-Q1    18.4
        50%   Med       -8.4      90%        7.      Mode       0.
        25%   Q1       -18.4      10%      -50.
        0%    Min     -1040.      5%       -82.
                                  1%      -480.
```

The definition of ATYDEVAL is given in Box 45.

Box 45. ATYDEVAL definition

```
if DEFENDER = 'Arabs'     then ATYDEVAL =  -5.
if DEFENDER = 'Austria'   then ATYDEVAL =  10.
if DEFENDER = 'England'   then ATYDEVAL =  20.
if DEFENDER = 'European'  then ATYDEVAL =  -5.
if DEFENDER = 'France'    then ATYDEVAL =  15.
if DEFENDER = 'Germany'   then ATYDEVAL =   0.
if DEFENDER = 'Israel'    then ATYDEVAL =  10.
if DEFENDER = 'Italy'     then ATYDEVAL =450.
if DEFENDER = 'Japan'     then ATYDEVAL =  -5.
if DEFENDER = 'Other'     then ATYDEVAL =  25.
if DEFENDER = 'Russia'    then ATYDEVAL = -60.
if DEFENDER = 'USA'       then ATYDEVAL =   0.
```

The error distribution for defender artillery losses is not normal, so the calculations are performed as described for the surprise calculations. The output values are restricted to one significant digit.

4.7.5 Attacker Air Losses

AIRCRAFT LOSS PROPOSITION 1: The attacker's aircraft loss is a function of the following variables: the product of the log of the attacker's width and the defender's artillery, the log of the battle duration, the log of the aircraft sortie force ratio, the battle duration, the attacker's force size, the product of the attacker's force size and the defender's sortie rate, the log of the artillery force ratio, the product of the defender's force size and the attacker's sortie rate, the defender's sortie rate, the visibility, the defender's nationality, the attacker's sortie rate, and a random variate. The equations in Box 46 estimate the attacker's aircraft losses.

The variables used in the regression to compute the sortie force ratio were the total sorties for each side (X0SORT and Y0SORT). Because the daily sorties were computed by dividing the total sorties by the duration, a pure force ratio of daily sortie rates (X0SORTD and Y0SORTD) would yield the same values, with the same coefficients. However, the addition of the small value (0.1) to each side's total sorties changes this somewhat. Therefore a small change has been made in the model's code from the statement in Box 46. Given only the daily sortie rate expected for a battle, the total number of sorties is estimated by multiplying by the expected duration. (This procedure is equivalent to dividing the 0.1 by the expected duration to produce an addition term with the appropriate "smallness.")

The definition for AIXDEVAL is given in Box 47.

The error distribution for attacker aircraft losses is not normal, so the calculations are performed as described for the surprise calculations. The output values are restricted to one significant digit.

Box 46. Aircraft loss proposition 1

```
P_AIRLOSX = 7.8 - .0145*ln(WIDTH)*Y0ART - 2.8*P_ln(DURAT)
        - .21*ln((0.1 + X0SORT)/(0.1 + Y0SORT)) + 1.37*P_DURAT
        + .000139*X0 + .00122*(X0/1000)*Y0SORTD
        - 1.16*ln((1 + X0ART)/(1 + Y0ART))
        + .000153*(Y0/1000)*X0SORTD - .057*Y0SORTD - 4.0*VIS
        + .92*AIXDEVAL

if P_AIRLOSX > . then P_AIRLOSX = max(0,min(P_AIRLOSX,X0SORTD*P_DURAT))

P_AIRLOSX = 1.21*P_AIRLOSX + random variate
```

random variate

Mean	-0.9	Std Dev	3.0
Skewness	0.7	Kurtosis	17.3

Quantiles

100%	Max	18.6	99%	14.1	Range	35.
75%	Q3	0.0	95%	0.0	Q3-Q1	1.34
50%	Med	0.0	90%	0.0	Mode	0.
25%	Q1	-1.34	10%	-3.8		
0%	Min	-16.5	5%	-6.1		
			1%	-11.3		

Box 47. AIXDEVAL definition

```
If DEFENDER = 'Arabs'     then AIXDEVAL =   0.
If DEFENDER = 'Austria'   then AIXDEVAL =   0.
If DEFENDER = 'England'   then AIXDEVAL =   0.
If DEFENDER = 'European'  then AIXDEVAL =  10.
If DEFENDER = 'France'    then AIXDEVAL = -10.
If DEFENDER = 'Germany'   then AIXDEVAL =   0.
If DEFENDER = 'Israel'    then AIXDEVAL =  -5.
If DEFENDER = 'Italy'     then AIXDEVAL =   0.
If DEFENDER = 'Japan'     then AIXDEVAL =   0.
If DEFENDER = 'Other'     then AIXDEVAL =  -5.
If DEFENDER = 'Russia'    then AIXDEVAL = -15.
If DEFENDER = 'USA'       then AIXDEVAL =   0.
```

4.7.6 Defender Air Losses

AIRCRAFT LOSS PROPOSITION 2: The defender's aircraft loss is a function of the following variables: the battle duration, the defender's force size, the defender's casualties, the attacker's intelligence, the total artillery, the attacker's force size, the product of the attacker's combat effectiveness and the log of the attacker's width, the defender's morale, the defender's sortie rate, the season, the attacker's nationality, the defender's nationality, and a random variate. The equations in Box 48 estimate the defender's aircraft losses.

Box 48. Aircraft loss proposition 2

```
P_AIRLOSY = .72*P_DURAT + .000147*Y0 - .000189*P_CASY + 9.3*XINTEL
        - .0181*(X0ART + Y0ART) + .000148*X0 - 1.24*XCE*ln(WIDTH)
        + 4.6*YMORAL + .00041*(X0/1000)*Y0SORTD + .84*AIRYSEAS
        + .58*AIYATVAL + .88*AIYDEVAL

if P_AIRLOSY > . then P_AIRLOSY = max(0,min(P_AIRLOSY,Y0SORTD*P_DURAT))

P_AIRLOSY = 1.12*P_AIRLOSY + random variate
```

random variate

Mean	-0.6	Std Dev	2.6
Skewness	1.0	Kurtosis	26.

Quantiles

100%	Max	19.4	99%	9.6	Range	32.
75%	Q3	0.0	95%	0.0	Q3-Q1	0.47
50%	Med	0.0	90%	0.0	Mode	0.
25%	Q1	-0.47	10%	-2.4		
0%	Min	-12.4	5%	-3.9		
			1%	-11.8		

The definitions of AIYATVAL, AIYDEVAL, and AIRYSEAS are given in Box 49, Box 50, and Box 51, respectively.

Box 49. AIYATVAL definition

```
if ATTACKER = 'Arabs'     then AIYATVAL =  -0.
if ATTACKER = 'Austria'   then AIYATVAL =   0.
if ATTACKER = 'England'   then AIYATVAL =   0.
if ATTACKER = 'European'  then AIYATVAL =   0.
if ATTACKER = 'France'    then AIYATVAL =   0.
if ATTACKER = 'Germany'   then AIYATVAL =  -5.
if ATTACKER = 'Israel'    then AIYATVAL =   0.
if ATTACKER = 'Italy'     then AIYATVAL =   0.
if ATTACKER = 'Japan'     then AIYATVAL =   0.
if ATTACKER = 'Other'     then AIYATVAL =   0.
if ATTACKER = 'Russia'    then AIYATVAL =   5.
if ATTACKER = 'USA'       then AIYATVAL =   0.
```

Box 50. AIYDEVAL definition

```
if DEFENDER = 'Arabs'     then AIYDEVAL =   0.
if DEFENDER = 'Austria'   then AIYDEVAL =   0.
if DEFENDER = 'England'   then AIYDEVAL =   5.
if DEFENDER = 'European'  then AIYDEVAL =   0.
if DEFENDER = 'France'    then AIYDEVAL =  -5.
if DEFENDER = 'Germany'   then AIYDEVAL =   0.
if DEFENDER = 'Israel'    then AIYDEVAL =   0.
if DEFENDER = 'Italy'     then AIYDEVAL =   0.
if DEFENDER = 'Japan'     then AIYDEVAL =   0.
if DEFENDER = 'Other'     then AIYDEVAL =   0.
if DEFENDER = 'Russia'    then AIYDEVAL = -15.
if DEFENDER = 'USA'       then AIYDEVAL =   0.
```

Box 51. AIRYSEAS definition

if SEASON = '-'	then AIRYSEAS = 2.
if SEASON = 'FT'	then AIRYSEAS = -2.
if SEASON = 'ST'	then AIRYSEAS = -2.
if SEASON = 'SpT'	then AIRYSEAS = -1.
if SEASON = 'WT'	then AIRYSEAS = 0.

The error distribution for defender aircraft losses is not normal, so the calculations are performed as described for the surprise calculations. The output values are restricted to one significant digit.

4.8 CALCULATING ADVANTAGE AND PREDICTING VICTORY

VICTORY PROPOSITION 1: PSV is a function of the attacker's force size, the defender's force size, the attacker's casualties, and the defender's casualties. The impact of attrition on victory in battle is mediated by comparative fractional attrition rates, expressed by the PSV parameter. PSV is calculated as shown in the equations in Box 52.

Box 52. Victory proposition 1

$$V = \ln((X0^2 - (X0 - P\_CASX)^2)/(Y0^2 - (Y0 - P\_CASY)^2)) - 2*\ln(X0/Y0)$$

$$PSV = 1 - 1/(1 + \exp(-1.75*\mathrm{sign}(V)*\mathrm{abs}(V)^{.75}))$$

VICTORY PROPOSITION 2: FPSADVNC is a function of the advance rate. The impact of advance rate on victory in battle is mediated by the FPSADVNC factor. FPSADVNC is calculated as shown in the equation in Box 53, Box 54.

Box 53. Victory proposition 2

$$FPSADVNC = \frac{10*(\exp(.033 + .264*P\_ADRAT) - 1)}{(\exp(.033 + .264*P\_ADRAT) + 1)}$$

VICTORY PROPOSITION 3: Success in battle is a function of the following variables: FPSADVNC, PSV, leadership, the attacker's initiative, the product of a function of starting date and the presence of armor, surprise, the attacker's nationality, the defender's nationality, and normal random variate. The impact of advance rate on victory in battle is mediated by the FPSADVNC factor. Success in battle is estimated by the equations in Box 53, Box 54.

It must be noted that extension of the SUCCESS forecast beyond the date of the last battle in the database is **extrapolation**, which is less reliable than **interpolation**. The sense of the STARTDAT variable in the model is for higher success rates for the attacker as time progresses. Conservative forecasts should consider this factor.

Box 54. Victory proposition 3

```
P_SUCCESS = -3.9 + .31*FPSADVNC + 4.3*PSV + 1.48*LEADER3
        + 1.23*XINITI - .000072*(STARTDAT + 17000)*ARMOR
        + .48*P_SURP + .99*VATVAL + 1.01*VDEVAL

P_SUCCESS = -.20 + .94*P_SUCCESS + normal random variate

if P_SUCCESS < -8 and P_SUCCESS <> . then P_SUCCESS = -8
if P_SUCCESS >8 then P_SUCCESS = 8

normal random variate
        Mean      0
        Std Dev   2.4
```

The definitions of VATVAL and VDEVAL are given in Box 55 and Box 56, respectively.

Box 55. VATVAL definition

if ATTACKER = 'Arabs'	then VATVAL =	.6
if ATTACKER = 'Austria'	then VATVAL =	-.4
if ATTACKER = 'England'	then VATVAL =	.2
if ATTACKER = 'European'	then VATVAL =	-.3
if ATTACKER = 'France'	then VATVAL =	-.5
if ATTACKER = 'Germany'	then VATVAL =	-.9
if ATTACKER = 'Israel'	then VATVAL =	-1.2
if ATTACKER = 'Italy'	then VATVAL =	-1.7
if ATTACKER = 'Japan'	then VATVAL =	.0
if ATTACKER = 'Other'	then VATVAL =	-.7
if ATTACKER = 'Russia'	then VATVAL =	.3
if ATTACKER = 'USA'	then VATVAL =	.0

Box 56. VDEVAL definition

if DEFENDER = 'Arabs'	then VDEVAL =	1.2
if DEFENDER = 'Austria'	then VDEVAL =	2.0
if DEFENDER = 'England'	then VDEVAL =	.7
if DEFENDER = 'European'	then VDEVAL =	1.6
if DEFENDER = 'France'	then VDEVAL =	1.3
if DEFENDER = 'Germany'	then VDEVAL =	.8
if DEFENDER = 'Israel'	then VDEVAL =	.9
if DEFENDER = 'Italy'	then VDEVAL =	.8
if DEFENDER = 'Japan'	then VDEVAL =	.9
if DEFENDER = 'Other'	then VDEVAL =	.6
if DEFENDER = 'Russia'	then VDEVAL =	.0
if DEFENDER = 'USA'	then VDEVAL =	.0

The error distribution for the advantage prediction is normal, so the calculations are performed as described for the log duration prediction. The output values are restricted to one decimal place.

Because the advantage values are restricted to the -8.0 to +8.0 range, the predictions are truncated if they extend beyond that range.

The final victory prediction is achieved by using the logic in Box 57 for each success prediction, low, expected, and high.

Box 57. Converting success to victory

SUCCESS < -1	VICTOR = DEFENDER
SUCCESS > +1	VICTOR = ATTACKER
	otherwise DRAW.

4.9 CALCULATING THE HELMBOLD SPACE GRAPH

The graph of Helmbold Space, shown in Fig. 10, is produced by plotting the coordinate data shown in Table 1. The LFORRAT value is the coordinate of the horizontal axis and the LHELMRAT value is the coordinate of the vertical axis. (Note that each of the ellipses is divided into two sections of coordinates, one representing the upper half and one the lower half of the ellipse and that the last value of the core group ellipse, which is a repeat of the last value of the first section is not listed to allow the table to fit on one page.)

The data points representing "This battle" in Fig. 10 use the value of LFORRAT calculated for the current scenario and the values LHELMLO, LHELMEX, and LHELMHI, log HELMRAT variables based on the low, expected, and high casualty predictions.

Table 1. Data for ellipses in Helmbold Space

CORE GROUP ELLIPSE

LFORRAT	LHELMRAT
-1.05316	-1.57974
-1.09662	-1.31039
-1.04556	-1.10406
-0.97763	-0.90894
-0.90055	-0.71999
-0.81712	-0.53524
-0.72893	-0.35367
-0.63686	-0.17467
-0.54152	0.002127
-0.44328	0.177008
-0.34244	0.350148
-0.23918	0.521677
-0.13363	0.691585
-0.02590	0.860231
0.083974	1.027350
0.195977	1.193051
0.310121	1.357325
0.426458	1.520137
0.545077	1.681428
0.666112	1.841109
0.789758	1.999048
0.916291	2.155062
1.046108	2.308888
1.179790	2.460136
1.318243	2.608205
1.462991	2.752076
1.616994	2.889777
1.787811	3.016270
2.053160	3.079740
-1.05316	-1.57974
-0.78781	-1.51627
-0.61699	-1.38977
-0.46299	-1.25207
-0.31824	-1.10820
-0.17979	-0.96013
-0.04610	-0.80888
0.083708	-0.65506
0.210241	-0.49904
0.333887	-0.34110
0.454922	-0.18142
0.573541	-0.02013
0.689878	0.142674
0.804022	0.306948
0.916025	0.472649
1.025902	0.639768
1.133638	0.808314
1.239181	0.978322
1.342443	1.149851
1.443289	1.322991
1.541522	1.497872
1.636868	1.674678
1.728932	1.853672
1.817129	2.035244
1.900557	2.219995
1.977689	2.406944
2.045568	2.604063
2.096629	2.810391

OUTER LIMIT ELLIPSE

LFORRAT	LHELMRAT
-1.56299	-3.13639
-1.92740	-2.49009
-1.83483	-1.18064
-1.61785	-0.39010
-1.33731	0.366707
-1.00696	1.097073
-0.63187	1.803690
-0.21204	2.486558
0.257599	3.142982
0.790796	3.765672
1.338108	4.267654
1.941494	4.626654
2.562995	4.636392
-1.56299	-3.13639
-0.94149	-3.12665
-0.33810	-2.76765
0.209203	-2.26567
0.742400	-1.64298
1.212046	-0.98655
1.631875	-0.30369
2.005965	0.402926
2.337316	1.133292
2.617850	1.890101
2.834833	2.680645
2.927403	3.990093
2.562995	4.636392

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157. The RAND Corporation, 1700 Main St, PO Box 2138, ATTN: System Science Department (Mr. Milton Weiner), Santa Monica, CA 90406-2138.
158. Dr. Daniel Willard, Department of the Army, SAUS-OR, The Pentagon, Washington, DC 20310-0102.
159. Ben P. Wise, McDonnell Douglas Research Laboratories, Dept 225 Bldg 105, Mail Code 1065165, PO Box 516, Saint Louis, MO 63166-0516.
160. J. Ralph Wood, 1727 Redgate Farms Ct., Rockville, MD 20850.
161. Maj Mark Youngren, U.S. Army Concepts Analysis Agency, 8120 Woodmont Avenue, Bethesda, MD 20814.